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THE loss of heat by radiation per unit of surface of a body in an enclosure of constant temperature depends upon two factors, (1) the nature of the surface, and (2) the excess of temperature of the surface over that of the enclosure. It is only, however, in vacuo that a body is ever cooled entirely by radiation. When the enclosure contains gas there is always surface conduction. When the excess of temperature is small, the loss of heat varies approximately as the product of this excess into a constant, the coefficient of emission or emissive power, which depends upon the nature of the radiating surface. In this, the simplest, case, we have

$$-\frac{d\theta}{dt}=c\theta \qquad (1)$$

as the expression for the rate of cooling, where θ is the excess of temperature, and c a constant.

Dulong and Petit have given the following formula, which agrees fairly well with the observed facts for a wide range of temperature:

$$-\frac{d\theta}{dt}=c\,(a^{\tau+\theta}-a^{\tau}) \qquad (2)$$

where θ is as before the excess of temperature of the radiating body, τ the temperature of the enclosure, c a constant depending on the nature of the body, and a an absolute constant which for the centigrade scale is 1·0077. Various other formulæ have

* This paper is intended to sketch an experimental method and to outline a discussion rather than to give a sustained and detailed account of results. A few of the measurements have been given, however, as illustrations.

[The work was begun in the Physical Laboratory at Edinburgh in the Summer of 1885.]

been deduced. In all of them the two factors mentioned above are of course involved; and it will be sufficient for our purpose to observe that for such differences of temperature as exist under normal circumstances between the skin and the air of a room, the rate of cooling of a thermometer or a small metallic ball is somewhat greater than that given by formula (1)—for a difference of temperature of 20°, not more than 6·5 per cent greater.

When we come to the problem of radiation from the skin of an animal, we find the difficulties which attend the subject even in the case of non-living matter much increased. We have no longer a radiating surface of definite and constant character. Not only may the difference of temperature between the skin and the environment change from time to time, but the physical condition of the epidermis itself may undergo variations, independent of or consequent upon, variations in the state of the corium. The factor c in equations (1) and (2) can no longer be assumed to be constant. Apparently from Masje's results (Virchow's *Archiv*, Bd. 107, pp. 17—71 and 267—290), the change in the emissive power of the skin may be so great, under certain conditions, as to mask and even to annul and reverse the effect of variations in the temperature. These conditions are, however, to a great extent abnormal. But in considering the part which radiation plays in the normal heat loss, we are met by the question, *What is the normal radiating surface in man and animals?* Is it really the naked epidermis? A little confusion on this point seems to exist in the minds even of some physiologists. Certain it is, that the enormous proportion of the heat lost by radiation to the total heat loss, which is observed when the skin is exposed in a physiological experiment, is not a normal ratio. Even in the case of the lower animals it can exist only under highly artificial conditions. In the first place only a small proportion of the naked epidermis is exposed under normal circumstances, and under the conditions which favour a rapid radiation. In man cooling by radiation is practically confined, outside the tropics, and in civilized races, to radiation from the clothes. In warm-blooded

animals it is confined to radiation from hair or feathers. In no case can the coefficient of emission of the real radiating surface alter much. It is again a non-living surface, whose properties may indeed be altered by physical changes in the air, but the radiation from which must be chiefly affected by changes in the temperature-difference between it and its surroundings.

But secondly, it is only when the body is at rest in still air that radiation can play a great part even in cooling the covering of the skin. When either the body or the air is in motion much of the heat lost must be given off by conduction and convection. Even a body with lamp-blacked surface, cooling in a closed space with lamp-blacked boundaries, loses only about half its heat by radiation, the other half being carried away by the air.

In normal circumstances, then, radiation is not the chief way in which the body loses heat. Further, what radiation there is is chiefly from surfaces whose excess of temperature is maintained by conduction from the epidermis, and the emissive power of which cannot alter much. A regulation of the heat loss by alterations in the amount of radiation cannot take place to any great extent by changes in the emissive power of the epidermis, cannot probably take place at all by alterations in the emissive power even of the physiological protective coverings. If such a regulation exists, it must be by means of changes in the conducting power of the epidermis, and of the temperature of the radiating surface.

This paper includes (1) observations on the temperature of the skin of man when covered and exposed, and on the temperature of the surface of physiological and artificial protective coverings in man and one or two animals; (2) measurements of the amount of radiation from the normal radiating surfaces, and from skin which is normally covered; and (3) simultaneous measurements of temperature and radiation.

Methods and instruments used.

The relation between the temperature and the resistance of a metallic conductor gives us the means of constructing thermometers and radiometers of great accuracy and sensitiveness, and

of late years the principle has been more and more applied in physical investigations in the domain of heat. It has also been introduced into physiology. Masje in 1887, in an elaborate research on radiation from the human skin, of which we shall have more to say later on, used a grating of tinfoil as radiometer; and quite lately Rolleston has attempted, with a negative result, to detect an increase of temperature in active nerves by means of a resistance thermometer of platinum wire. (*Journal of Physiology*, XI., 208–225). More than three years ago I made a similar attempt with a grating of gold leaf, prepared by fastening the leaf upon a large coverslip, and then cutting the grating out, the whole being covered with a thin layer of varnish. Six sciatic nerves of the frog were arranged on one grating and covered with another, the two being connected in series, and balanced by a similar pair. The result of the first experiments was, like Rolleston's, negative, but the work had to be broken off before enough had been done to warrant a definite conclusion, and it was never resumed. Before the gold leaf had been tried an attempt was made to produce a grating on glass by the process of electro-gilding, with fair success; but it was feared that the plumbago lines upon which the gold was deposited might affect the accuracy of the apparatus, and it was not used. In this work I have employed gratings of lead paper.

I. Measurement of the temperature of the radiating surfaces.

I do not know of any investigation of the temperature of the skin which has been made before with an apparatus of this kind; yet the method marks itself out as pre-eminently suitable for the measurement of the temperature of surfaces. What is required here is an instrument which can be accurately adjusted to the surface, which will quickly and certainly acquire the same temperature, and which at the same time will not sensibly alter that temperature by preventing the free radiation and conduction of heat. The resistance thermometer fulfils the first condition because it is easy to give

it any form. It fulfils the second, bcause its capacity for heat can be made extremely small by using very thin wire or foil, by which at the same time its sensitiveness is increased. It fulfils the third condition, both on account of its small capacity, and because it can be so arranged that the average temperature of an area can be found without covering more than a portion of it. It has great advantages over the thermopile because of its small mass, its plasticity of form, the quickness with which it comes to its position of equilibrium, and the fact that the resistance is approximately proportional to the temperature. Its greater sensitiveness is an advantage for some purposes, but not for measuring the temperature of the skin. It is of course no disadvantage, because it can be easily reduced. All this is true of almost any form of resistance thermometer. Another advantage, for work where extreme accuracy is not required, is that anybody who can measure a resistance can make himself a sensitive thermometer in a very short time out of the commonest materials. I used three forms in measuring the temperature of the skin. In making the first, a piece of ordinary lead paper was fastened to a coverslip with shellac varnish. It was then cut out into a grating, with a sharp pointed knife, each bar being about a millimeter in breadth, and the distance between two adjacent bars being about half a millimeter. The coverslip was fastened to a simple wooden holder, the grating covered with a slip of the thinnest glass, and the unscored ends of the lead paper were turned up round the holder, and tacked to it by a small copper nail on each side, which was soldered to copper connections. The resistance was between three and four ohms and the area of the sensitive surface a little more than a square centimeter. It would be perfectly easy to make the area very much less than this, but what I wanted to measure was not the very small differences of temperature which can exist in neighboring portions of the skin, but the average temperature of areas of moderate size.

This grating was balanced by another of precisely similar construction, the two forming the arms of a Wheatstone's bridge, which was completed by a graduated wire with a sliding contact.

Two methods of observation were used. In the first the bridge was balanced, one of the gratings applied to the skin (the same one was always employed), and the resulting deflection read off. This is porportional to the difference of temperature between the two gratings, and by an experimental graduation the value of the deflection in degrees is obtained, this value being the excess of temperature of the skin over that of the air. In the other method two equal resistances were introduced one at each end of the bridge wire. The resistances were of such amount that with the maximum difference of temperature between the gratings the slider had to be moved over three-quarters of the length of the wire in order to restore the balance. Instead of reading the deflection, the position of the slider with null deflection was read before and after the application of the grating to the skin. The experimental graduation gave the difference of temperature corresponding to a given difference of position of the slider. Experiments 1 and 2 are examples of the two methods. In using the first method it was necessary to be careful that the battery was always set up in the same way, so as to have a constant E.M.F. and resistance.

EXPERIMENT 1. Deflection read { Δ = difference of temperature between the part and the air of the room. T = temperature of the part. }

Region.	Deflection.	Δ	T	Temperature of room.
Anterior surface of left forearm.	222	16·8	34·4	17·6
Posterior surface of left forearm.	218	16·4	34·0	17·6
Anterior surface of left arm over belly of biceps.	232	17·6	35·0	17·4
Left leg over head of tibia.	190	14·4	31·9	17·5
Skin just below xiphoid cartilage.	226	17·2	34·7	17·5
Skin over sternum.	206	15·6	33·2	17·6
Trousers over anterior surface of left thigh (nothing between trousers and skin).	82	6·1	23·7	17·6

EXPERIMENT 2. Position of the slider read.

Region.	Δ	T	Temperature of room.
Palm of left hand.	12·58	30·95	18·37
Forehead.	14·70	33·04	18·34
Right cheek.	14·92	33·21	18·29
Left breast.	16·01	34·40	18·39
Right hypogastrium.	17·00	35·16	18·16
Over apex beat.	16·32	34·57	18·25
Sole of left foot.	12·75	31·05	18·30

The second form of grating was designed to allow part of the area whose temperature was being measured to be still in free communication with the air, or perhaps more correctly to measure the average temperature of alternate strips of the given area. A lead paper grating was cut out on thin card-board, the latter being cut clean away in the intervals between the bars of the grating. The breadth of an interval was the same as that of a bar. The surface was lightly varnished, and the whole mounted in a handle attached to one side. Experiment 3 is an example of the results with this grating.

EXPERIMENT 3. The measurements were made immediately after those of Experiment 2, on the same parts, and as far as possible under the same conditions.

Region.	Δ	T	Temperature of room.
Palm of left hand.	12·83	30·99	18·16
Forehead.	14·41	32·71	18·30
Right cheek.	14·63	33·07	18·44
Left breast.	15·93	34·18	18·25
Right hypogastrium.	16·82	35·07	18·25
Over apex beat.	16·68	34·68	18·00
Sole of left foot.	12·50	30·61	18·11

A third form of lead paper grating was devised to allow the outer surface of the metal to be freely exposed to the air. The grating was attached to a narrow frame of cardboad, and sup-

ported by a wide-meshed silk netting on its outer surface, while the surface next the skin was varnished. With care it was possible to get steady contact without injuring the grating.

Experiment 4 is an example. The measurements were made immediately after those of the last experiment.

EXPERIMENT 4.

Region.	Δ	T	Temperature of room.
Palm of left hand.	12·44	30·72	18·28
Forehead.	14·14	32·60	18·46
Right cheek.	14·87	33·00	18·13
Left breast.	15·91	34·01	18·10
Right hypogastrium.	16·56	34·83	18·27
Over apex beat.	16·12	34·42	18·30
Sole of left foot.	13·00	30·84	17·84

In each experiment the temperature of the parts usually covered by the clothes was taken immediately after exposure, and the results of such measurements are fairly uniform. Experiments 3 and 4 shew temperatures which do not differ much from those of Experiments 1 and 2; but on the whole the temperatures are somewhat lower in the former. This was found to depend not upon cooling due to previous exposure, but upon the kind of instrument used. The first form described reads a little too high, probably because the free radiation and conduction of heat is interfered with, and the evaporation of sweat checked, more than when the other forms are used. Still it is fairly accurate and suitable for every purpose of relative temperature measurement, although not so suitable as the others when the actual temperature of a part has to be determined to the second decimal.

But almost any form of resistance thermometer would be a great improvement upon the mercury thermometer for measuring skin temperatures. The great constancy of the readings for parts of the skin where the temperature has reached its stationary state, *e.g.*, the hands or face of a man who has sat for some

time at rest in still air, or a part of the usually covered skin which has cooled to its minimum, is a good proof of the reliability of the method.

When a part of the body which is normally covered is exposed to the air of a cool room the temperature declines progressively to a minimum, which, with small variations, it maintains. Experiments 5 and 6 are Examples.

EXPERIMENT 5.

	Time.	Δ	T	Temperature of room.
Anterior surface of left forearm exposed at 4.10....	4.10	15·23	33·43	18·20
	4.17	14·81	33·23	18·42
	4.23	14·10	32·66	18·56
	4.29	13·77	32·37	18·60
	4.37	13·11	31·71	18·60
	4.42	13·40	32.02	18·62
	4.55	13·40	32·02	18·62

The temperature remained constant at about 32·0 for 20 minutes longer, when the experiment was broken off.

EXPERIMENT 6.

	Time.	Δ	T	Temperature of room.
Anterior surface of left forearm exposed at 5.5.....	5.4	—	—	—
	5.5	11·82	32·43	26·61
	5.15	11·04	31·64	20·60
	5.24	9·40	30·03	20·63
	5.83	9·65	30·25	60·60
	5.40	9·42	30·02	20·60

The cooling is not uniform over the whole of the exposed surface. In general the extensor surfaces of the limbs cool more quickly than the flexor, but sometimes there may be little difference. The decline of temperature is especially marked where there is no great thickness of muscle between the skin

and the bone, or where there are only tendons. The skin over the patella and shin cools rapidly, while the temperature of the back of the hand is nearly always less than that of the palm.

The temperature of the surface of the clothes in man and of the hair of animals is a very important element in determining the amount of radiation. It depends chiefly upon the temperature of the epidermis, the conductivity of the coverings, and the temperature of the air. It must be remembered that air when not free to move is a very bad conductor of heat, and the air between the clothes and the skin and in the pores of the clothes, and between the hairs and feathers of animals, is a most important protective covering. The aqueous vapour in the air also absorbs radiant heat from a low temperature source with great readiness, as Tyndall has shewn (*Phil.Trans.* 1861) ; and still air near the skin must be saturated or nearly saturated.

The difference of temperature between the surface of the clothes and the air will determine the amount of radiation and conduction, and it is certain that in man a great part of the heat regulation consists in keeping this difference approximately constant. If the temperature of the air falls, that of the surface must fall too, unless the loss of heat is to increase. Between the surface of the clothed skin and the outer surface of the clothes the slope of temperature must become steeper. Now the flow of heat by conduction is proportional to the slope of temperature and the specific conductivity, and inversely proportional to the thickness of the conductor. The flow must be quickened when the slope of temperature becomes steeper, the other factors remaining unaltered. But if the thickness of the conductor be increased or its specific conductivity diminished, the flow may be kept the same as before. This is, of course, what happens when additional clothes, or clothes of a warmer kind are put on in cold weather. When this compensation is not complete, the slope of temperature may be made less steep by warming the air artificially. When from any cause compensation cannot be obtained by variations in the factors governing the outflow of heat, the increased flow may be balanced by an increased production, due either to visible muscular contractions,

voluntary or involuntary, or to increased metabolism unaccompanied by such contractions. Heat regulation by alteration in the heat production seems to be more complete in the lower animals than in man (Loewy, Pflüger's *Archiv,* Bd. 45, S. 625). This is what we should expect, not only on account of the smaller size of the animals generally used for experiment, but because animals of any size have very little voluntary control over the difference of temperature of the radiating surface and the surroundings.

I have measured the temperature of the real radiating surfaces in a man clothed in the ordinary way and seated in a still atmosphere, and at the same time measured the radiation. The temperature of the room varied from 17° C. to a little over 20° C. The excess of temperature of the surface of the clothes varied from 6°·1 over the thigh, which was covered only by the trousers, to 1°·51 outside of the coat when it was buttoned up. Outside of the waistcoat it was in one experiment 4°·17. Between the waistcoat and the skin there was a linen shirt and a flannel undershirt. The coat sleeve over the fore-arm had an excess of 4°·32; over the upper-arm, of 3°·88. The excess of temperature did not vary much for a change of a few degrees in the temperature of the room.

The rest of the radiating surface, the skin of the hands, neck, and face, and the hair, had of course a much greater excess of temperature, ranging from 11°·61 on the palm and 10°·83 on the dorsum of the hand to 14°·54 at the side of the neck, and 13°·86 on the cheek, the surface of the hair having an excess of 7°·4.

The skin of a guinea-pig at one place had a temperature of 34°·50, the surface of the hair over it a temperature of only 29°·11; the skin at another place 35°·83, surface of hair, 29°·56; the skin of a rabbit, 36°·80, hair over it, 31°·54.

II. Measurement of the quantity of heat radiated.

Arrangement. I used at first a thermopile, but soon abandoned it for a lead paper grating fastened on a frame of stout cardboard, and blackened on one surface. It was balanced in the Wheatstone's bridge by a similar grating, and the measure-

ments were taken in the manner described for the temperature. The grating which received the radiation was of course kept at a constant distance ($4\frac{1}{2}$ centimetres) from the radiating surface.

The amount of radiation varied greatly at different parts of the surface. Over the clothes it was nearly proportional to the excess of temperature, as was to be expected, the outside clothes being all of the same material. The radiation from the exposed skin was also approximately proportional to the excess of temperature, but in a higher ratio, the skin having a greater coefficient of emission than the clothes (these were of light grey material). The total radiation under the most favourable circumstances did not exceed the rate of 700,000 calories in 24 hours for a body-weight of 70 kilogrammes. Taking the surface and, therefore, the radiation as proportional to the body-weight, this would give 820,000 calories for a bodyweight of 82 kilogrammes. Helmholtz has calculated the total heat loss from the skin, by evaporation, radiation, and conduction, for a man of 82 kilogrammes weight, at about 2,180,000 calories for a temperature of the air of 20°. If we substract 280,000 calories for evaporation, we get about 1,800,000 calories as the loss by radiation and conduction together; and of this the radiation would account for less than half.

Masje calculated from his results, that the quantity of heat radiated from the body of a man of 82 kilogrammes weight was 1,728,000 calories, which agrees, according to him, almost precisely with the calculated heat loss by the skin, exclusive of that due to evaporation. This leaves scarcely anything for conduction, which is certainly a mistake. It is beside the point to say that "the conductivity of still air is very small, almost 20,000 times smaller than that of copper." Under the conditions of his experiments and indeed under any circumstances in which the skin is exposed to the air of a room, conduction and convection must play a great part. The reason why Masje got such a high value for the radiation is not because the other portions of the heat loss were very small, but because the total heat loss in his experiments was very great, much greater than the normal. The agreement of his calculation for radiation

alone with Helmholtz's calculation for radiation and conduction together is only accidental. What Masje measured was the heat radiated from the *naked skin* in a cool room; and nobody can doubt that the total heat loss, with an air temperature of 10°—15° C. must be greater when the body is naked than when it is clothed. This is true, not only when the whole body is actually stripped, but also when the heat loss is reckoned from that of a number of limited areas, singly and successively exposed. If Masje had measured the total heat loss by radiation and conduction, under the conditions of his experiments, he would have found that the fancied agreement disappeared, and the disappearance of it would be a necessary proof of the correctness of his results. The mistake, however, can only be considered as a slip in a very thorough and scientific paper; but it is well to point out that Masje's whole investigation, interesting as it is, has only a limited application to the question of heat radiation from the body under normal conditions.

For example, in one of my experiments the heat radiated from unit area of the palm of the hand was to that radiated from the surface of the sleeve of a thin flannel shirt over the anterior surface of the corresponding forearm, as 204 to 42, or in round numbers 5 to 1. The radiation from the naked skin of the anterior surface of the forearm was to that from the same thin covering as 270 to 42, or more than 6 to 1, while its proportion to the radiation from the surface of the coat was as 270 to 28, or nearly 10 to 1. From the cheek the radiation was almost exactly six times as great as from the flannel covering the forearm. It is evident that if we were to take the radiation from the naked skin as the measure of the normal heat loss by radiation, the value would be far too high; for the clothes are warmed chiefly by conduction.

We have seen that there are two factors which may affect the amount of radiation, the temperature difference and the emissive power. Masje could not find any decided influence of the former on the radiation from naked skin; but he found that the emissive power varied in a very remarkable manner. He found that when the whole body or a large part of it was exposed to the

air of a cool room, the radiation increased with the time of exposure; and when the temperature of the room was only 9°—10° C., it might in less than an hour reach double or even quadruple its initial amount. He ascribes this to changes, perhaps partly produced reflexly through nervous influence, which alter the emissive power of the surface. I do not dispute the accuracy of the observations on which he rests his conclusions, although I am unable from my own experiments to confirm them, as I worked with a higher temperature of the air. It is to be expected that physical changes in the radiating surface, such as must take place in the skin both from physical and physiological causes, affecting notably the amount of moisture contained in its superficial layers and on its surface, should affect also the emissive power. And although the outer layer of the epidermis can scarcely be susceptible to direct nervous influence, yet it is not impossible that changes in the rete Malpighii brought about through efferent nerves acting directly on its cells may have the supposed effect. On the other hand there are so many known factors by which the amount of radiation, as measured by a pile or a bolometer, may be influenced, that it is only when these are obviously insufficient to explain a phenomenon, or when there is strong direct evidence that they are not connected with it, that we should call in the aid of "direct nervous action."

There is one factor which must affect all radiation experiments on the animal body, and especially on the human skin; and that is the quantity of sweat given off. Apart from its effect on the temperature of the skin, which will influence the quantity of heat emitted, the amount of watery vapour, and perhaps of other substances such as the aromatic bodies in sweat, in the layer of air next the skin, will affect the proportion of the radiated heat which reaches the recording instrument. The absorptive power of water vapour for radiant heat from a source at the temperature of the surface of the body is very great. Carbonic acid gas is also a very much better absorber than dry air. Certain organic vapours in very minute traces almost prevent radiant heat from passing. In

still air there must be a layer next the skin which contains more watery vapour than the atmosphere. When the sweat glands are active this layer will be of greater thickness and more highly charged with watery vapour, carbonic acid, and possibly with other substances which are even better absorbers of radiant heat, than when the secretion of sweat is slow or in abeyance.

If we take the quantity of water given off as insensible perspiration for an average adult, at, say, 650 c.c., it is easy to calculate the volume of dry air which would be saturated by it for any given temperature. One gramme of aqueous vapour can saturate, in round numbers, 33,000 c.c. of dry air at 30° C., and 650 grammes would saturate 21,450,000 c.c. Taking the surface of the body at 20,000 sq. cm., we get about 1,070 c.c. of air saturated at 30° C. per centimeter of surface in the 24 hours. This is equal to about $\frac{3}{4}$ of a c.c. per minute. In a minute the evaporation from the skin would suffice to surround the body with a shell of air, saturated for the temperature of 30° C., of three-quarters of a centimeter in thickness, if there was no movement of the air.

Séguin's estimate of the material given off by the skin at $\frac{1}{67}$ of the bodyweight in 24 hours would correspond to about double this thickness of saturated air at 30° C.; and to a saturated layer 3 centimeters thick at 20° C. For originally dry air at 10° C. the layer would be rather less than 5 cm. in thickness; and for air originally half saturated at 10° C., the thickness of the layer raised to saturation point in a minute would be 10 cm.

Of course we cannot assume that saturation does actually go on in still air so quickly as this. But if we consider that the average rate of evaporation for the 24 hours over the whole surface may be much exceeded at certain times and for particular parts of the skin; and further that aqueous vapour does not necessarily diffuse away at the rate depending on its density but may be condensed on dust particles in the air and re-evaporated, we shall see that some absorption of the heat radiated from the body must take place between the instrument and the skin, and that this will be greater the more freely the sweat glands are acting.

A small apparent increase in the radiation when the skin is exposed for some time in a room, with a temperature of 17° C. to 20° C. might be explained as due to diminished activity of the sweat glands, and therefore to diminished absorption. But the increase observed by Masje with a temperature of the air of 10° C. and 13° C. is too great to be thus accounted for, and the initial intensity of radiation does not seem to leave room for a very extensive absorption. Besides, a *warm* bath seemed in his experiments to cause an increase of radiation, even after the skin temperature had sunk to normal. I cannot say that I have been able to satisfy myself that the increase of radiation which undoubtedly follows the use of a bath a few degrees higher than the skin is due to anything else than the increase of temperature of the radiating surface. But this may again be due to the temperature of the room being higher than in Masje's experiments.

The effect of some antipyretics in increasing radiation certainly seems to favour the view, that the emissive power is increased; but when an antipyretic causes flushing of the skin it must increase the *temperature* of the radiating surface. Antipyrin, as Masje rightly remarks, reduces the temperature in the axilla, at the same time that it increases the radiation from the skin. But reduction in the temperature of the axilla or in the temperature of the blood, is not the same as reduction of the temperature of the naked skin. The radiation from a flushed skin must come partly from a layer as deep as the most superficial bloodvessels, else we should not see the flush; and doubtless rays of greater wavelength than the extreme visible red can pass through the epidermis.

The greatest difficulty in the way of the explanation of such immense changes in the intensity of radiation as Masje saw, by changes in the emissive power, is their very magnitude. The emissive power of the skin under *normal* conditions is high. I have found that a thin layer of lampblack does not much increase the radiation from the palm. In some experiments it even seemed to diminish it. But there is a possible fallacy here. Some of the radiation from the skin certainly comes from the

deeper layers. The lampblack will absorb this, and being at a lower temperature at first it will not give it all out again. But dead skin is also a good radiator. Two equal cubes of thin metal were covered with human skin. The skin covering one of them was coated with lampblack on the outside. That covering the other received a similar coating on the inside before being put on, so that the conductivity might be the same in both. The cubes were filled with water at 40° C., and allowed to cool. The rate of cooling showed that the lampblacked surface did not radiate much faster than the skin. But if the emissive power of skin can be increased fourfold, it must before the increase be less than one-fourth that of lampblack. Masje found that when the skin of the arm was cooled 3° C. to 4° C. below the normal the radiation fell off instead of increasing, and he explains this as due to the effect of the diminished temperature more than counterbalancing the effect of the increased emissive power.

It is difficult to see why if the emissive power can be increased fourfold by cooling the surface, a decline of 3° C. in the surface temperature should have any sensible effect in checking the radiation. From equation (1), p. 101, we see that the radiation will remain constant if c is increased in the same proportion as θ is diminished. Taking 3°—4° as the utmost by which the temperature of the skin can be diminished without diminishing the radiation, we find that an increase of one-fifth in the coefficient of emission would in Masje's experiments be enough to balance the fall of temperature. But if an increase of fourfold is possible, why is an increase of a fifth not forthcoming?

If we take equation (2), p. 101, we get for the radiation from skin at 31° C., with a temperature of the room of 15° C., the expression

$$R = c(a^{31} - a^{15}) = ca^{15}(a^{16} - 1),$$

and for the radiation from the skin at 28° C.,

$$R' = c(a^{28} - a^{15}) = ca^{15}(a^{13} - 1) \therefore \frac{R}{R'} = \frac{a^{16} - 1}{a^{13} - 1}.$$

Now $$a = 1{\cdot}0077, \text{ and } \frac{R}{R'} = \frac{1306}{1049}, \text{ or about } \frac{5}{4}.$$

If we take $4°$ as the fall of temperature,

$$\frac{R'}{R} = \frac{1306}{964}, \text{ or about } \frac{4}{3}.$$

So far as the temperature factor is concerned the radiation would only be diminished by $\frac{1}{5}$ for a diminution of 3° C.; and by $\frac{1}{4}$ for a diminution of 4° C.; again we are confronted by the question why the increase in the emissive power, which can assume such proportions when the temperature is lowered by 2° C., should be unable to compensate for the trifling diminution of radiation ($\frac{1}{15}$ or $\frac{1}{12}$ at most) caused by a further lowering of 1° C. Either the emissive power cannot alter so much as Masje thinks, or it is not altered in the same sense, or in the same proportion if the sense be the same, for a fall of temperature of the skin of 3° C. as for a fall of 2° C. It will not do to say that it reaches a maximum when the skin is cooled, say 2° C. It must decline from this maximum or possibly sink even below its original amount, if Masje's explanation is to be held sufficient. The greater the changes in the emissive power which must be postulated in order to explain his results with moderate cooling, the more difficult does it become to give a consistent explanation of what happens when the cooling is carried a little farther. Even if we suppose that the greater part of the radiation is from layers below the surface, and that the absorptive power of the superficial layers for this radiation is the chief variable, the difficulty is still to explain how so large a variation can be brought about, and why it should so abruptly change its sign. With an external temperature of from 17° C. to 20° C. I have certainly found that the temperature of the skin is a far more influential variable than the emissive power. Masje, on the other hand, working with lower external temperatures, found just the reverse. No entirely satisfactory explanation occurs to me of this difference — discrepancy it can hardly be called, because there is no reason why the factors which determine the amount of radiation should affect it in the same way with a low, as with a moderately high external temperature. The influence of the temperature factor is very clearly seen in parts of the

skin which are normally exposed, while the emissive power of such parts remains approximately constant. Experiment 7 shews the effect of various conditions of such a surface and of changes of its temperature on the radiation. When the temperature of the hand is raised or lowered by immersion *for a short time* in a bath, the radiation is correspondingly increased or diminished. This contrasts with the behaviour of the normally covered skin as observed by Masje, who found that cold baths might greatly increase the radiation.

EXPERIMENT 7. Palm of left hand.

Time.	Condition of Surface.	Deflection.	
11.30 a.m.	Moist with sweat.	100	The temperature of the room during the observations varied from 20° C. to 20°·3.
11.32 "	Dried lightly with cloth.	130	
11.36 "	Washed in water at 20° and dried.	122	
12.30 p.m.	Felt cool.	98	
2.30 "	Immediately after walking—felt warm.	121	
2.40 "		126	
2.45 "	Covered with vaselin.	86	
2.50 "	Still covered with vaselin.	78	
2.55 "	Vaselin washed off—hand dried without rubbing.	126	
2.59 "	Palm covered with lamp-black.	101	
3.2 "	" "	105	
3.4 "	" "	112	
3.6 "	" "	98	
3.9 "	Lamp-black removed.	120	
3.10 "	" "	124	
3.15 "	Rubbed briskly with towel—felt very hot.	158	At 3.18 the radiation had sunk to 123.
3.20 "	Heated in dry air at 50° C. for 1 minute.	148	
3.25 "	After being 1 minute in bath at 19° C.; dried without rubbing.	96	
3.30 "		86	
3.35 "	After being 1 minute in bath at 27° C.	99	
3.40 "	After being 2 minutes in bath at 36° C.	134	
3.50 "	After being 2 minutes in bath at 46° C.	168	At 3.45 radiation was 125.

A division of the scale represents about ·000006 small calories (gramme-degrees) per second per cm. of surface.

III.—SIMULTANEOUS MEASUREMENT OF THE SURFACE TEMPERATURE AND THE RADIATION.

I do not propose to do more here than to describe the method of making the observations and to give a single example of

them, as I hope to have an early opportunity of returning to the subject in connection with some calorimetrical work.

Both the temperature and the radiation were measured as before by the resistance method, and the radiometer was the same lead paper grating as was previously used. The thermometer applied to the skin consisted of a narrow strip of varnished lead paper, forming the sides of a square whose internal area was equal to that of the sensitive part of the radiometer. It was attached to the radiometer at a distance of 4½ centimeters; so that when a part of the surface of the body was applied to the thermometer it was in the proper position for the measurement of the radiation. The instruments, balanced by two precisely similar arrangements, were each introduced into a Wheatstone's bridge, the two systems being quite separate and the galvanometers independent. The deflections were simultaneously read. Strictly speaking it was not the temperature of the radiating surface itself which was measured, but that of its boundary, which must be approximately the same when the area is not too large.

EXPERIMENT 8. Palm of right hand.

Condition.	Radiation.	Δ	T	Temperature of room.
Normal.	107	10·40	31·0	20·60
Arm held above head for 2′.	70	9·05	29·65	
Hand hanging down for 2′.	128	11·1	31·7	
Hand kept at level of heart for 2′.	120	10·4	31·0	
Band round wrist so as to prevent the venous return.	121	10·9	31·4	20·5
Hand immediately after bath at 18° for 2′.	90	9·50	30·11	20·61
Hand after brisk rubbing.	152	14·07	34·57	20·50
Hand after bath at 33° for 2′.	112	10·84	31·34	20·50
Hand after bath at 45° for 2′.	174	15·10	35·52	20·42

Δ means, as before, the excess of temperature of the skin over the air.
T the temperature of the skin.

It will be seen that the radiation from the palm is in most

cases approximately proportional to the temperature; and therefore the coefficient of emission for the palm may be looked upon as fairly constant. This does not apparently apply to the normally covered skin, nor to the skin in fever. Masje states that in fever the radiation is less than the normal, although the temperature of the skin is greater. This can scarcely be true of the whole heat loss by the skin, for, in fever, after the stationary temperature has been reached, the loss of heat must equal the production, and the production is increased. More heat must therefore be lost in other ways than is normal; by conduction and convection and by respiration that is to say.

The general conclusions to which I have been led are that under normal circumstances the heat loss cannot be regulated by alterations in the emissive power of the radiating surface either in man or animals, and that, for the external temperatures with which I have worked, no marked change in the emissive power of the human skin can be brought about by heating or cooling it. The difference of temperature between the radiating surface and the environment is therefore the chief factor which affects the heat loss. When this is increased the heat loss is in general increased, whether the greater difference of temperature be brought about by lowering the external temperature, or by increasing that of the radiating surface, or by substituting for the normal radiating surface another of higher temperature, or greater emissive power, or both.

When a large part of the skin of an animal which is normally protected by an artificial or natural covering is exposed to air at a temperature of 15° C. to 20° C., the loss of heat by the skin is increased; and it depends (*a*) upon the size of the body, (*b*) upon the perfection of the heat-regulating mechanism, whether the internal temperature falls or not. The larger the body the less must the proportional increase of the heat production be, in order that the internal temperature may remain constant.

In small animals, such as rabbits and guinea-pigs, it is astonishing how little an increased heat production can supply the loss of a considerable part of the protective covering, or make up for an alteration in it which increases the outflow of heat. It has long been known that a rabbit dies when its skin is varnished.

The superstition still lingers in some text-books that this is due to interference with the excretory functions of the skin. This explanation may perhaps hold good in the case of animals like the horse. It is not necessary for the case of the rabbit and the guinea-pig. For, without varnishing at all, if the hair be removed from the greater part of the body of either of these animals by rather close clipping or still better by shaving, and the animal be kept in an empty box so that it cannot cover itself, it dies in summer weather with an air temperature of 15° C. to 18° C., and that sometimes in 20 to 30 hours. The rectal temperature sinks fast, notwithstanding almost constant involuntary muscular contractions. If the radiation from the skin be measured, it is found to be far in excess of that from the hair. The animal is evidently losing heat more rapidly than it can produce it. The heat regulating mechanism is overmastered by the sudden increase in the heat loss from the skin. If now, before the cooling has gone too far, the animal be placed in a warm chamber, the rectal temperature rises again, and it recovers completely. The increase of heat production can only respond within somewhat narrow limits to an increased heat loss; and it would seem that if the heat production once begins to lag behind the heat loss, if a considerable diminution of the temperature of the blood has actually taken place, it becomes more and more difficult to restore the balance.

When the skin is varnished the same kind of thing goes on. The hair owes its low conducting power chiefly to the large amount of air which it keeps at rest around the animal. When it is varnished over, a great part of this air is expelled, the hair is flattened down on the skin, and the escape of heat is accelerated. The dilatation of the vessels which is said to take place under the varnish would increase this still more.[1] Possibly the emissive power of the varnish may be greater than that of the normal radiating surface. I have not, however, found this the case for the skin of man. At any rate, an alteration in the normal radiaing surface, whether produced by varnishing or by removal of the hair may be sufficient to baffle any attempt at making up the increased loss by increased production, and the lower the external temperature the more easily will this take place.

[1] Any direct or reflex "tonic" effect which the actual contact of the air may have on the skin is of course lost.